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Considerations in General Anesthesia for Cesarean Section in Small Animals

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Selection of the safest and most effective anesthetic protocol for performing a cesarean section is often a dilemma for veterinarians. Dams who are presented for this procedure are often in an emergency state, and their physical condition, along with that of the fetuses, is in a declining plane. Combining this with the fact that pregnancy, especially in the immediate prenatal period, causes significant alterations in maternal physiology, makes the correct choice of an anesthetic protocol vital.

The first rule to remember when choosing a specific protocol is that drugs used to produce chemical restraint and general anesthesia in the dam will also affect the fetus. Drugs that depress the dam, such as sedatives, tranquilizers, and anesthetics, must cross the blood-brain barrier to produce their effect. Therefore, it is impossible for the fetus to be unexposed, as the properties that allow the drugs to cross the blood brain barrier also promote placental transfer.[1,2] Along this same line, it must be remembered that the depressant qualities of anesthetics will be more pronounced and of longer duration in fetuses and neonates than in dams.

Satisfactory anesthesia can be induced in several ways, yet the objectives of all protocols should be similar. Drug combinations should be chosen to 1) provide optimal analgesia for surgery, 2) minimize fetal and postoperative maternal depression, 3) cause the least degree of physiological changes, and 4) neither induce nor prevent uterine contractions.[1,3-5]

Veterinarians need to be aware that no one protocol or drug combination is ideal for every situation. Choice of protocols should be based upon the clinician's skill and experience with specific agents, knowledge of the physiological alterations that occur during pregnancy, pharmacological effects of chosen anesthetics and their effects on the dam and fetuses, the advantages and disadvantages of a chosen protocol, and possible complications. Common sense and knowledge of the above, along with foresight in preparation for the surgery, can make general anesthesia for cesarean section safe and predictable.

Key Facts

- Chemical restraint and general anesthesia will also affect the fetus.
- Depressant qualities of anesthetics will be more pronounced and longer in duration in the fetus and neonate than in the dam.
- Drug combinations should:
  1. provide optimal analgesia for surgery,
  2. minimize fetal and postoperative maternal depression,
  3. cause the least degree of physiological changes, and
  4. neither induce nor prevent uterine contractions.

Physiological Changes Induced by Pregnancy

Anesthetic considerations for cesarean section must be based on the fact that certain physi-

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ological alterations are induced by pregnancy and parturition. These changes profoundly influence the specific anesthetic agents and dosages chosen to be used for the procedure. Table I lists the physiologic alterations that may be encountered.[1,4-6]

Cardiovascular System The cardiovascular system of the pregnant animal experiences several changes during pregnancy and parturition that affect the response to anesthetic agents. Maternal blood volume increases by 30-40%. This is primarily attributable to a rise in plasma volume rather than red cell mass.[4,6] This results in a relative dilutional anemia, as hemoglobin concentration and packed cell volume are decreased, thereby reducing the oxygen carrying capacity of blood.[4] Pregnancy also triggers a rise in maternal heart rate and cardiac output, which can reach a level 30-50% above normal near term, and an additional 10-25% above normal during labor as a result of blood being extruded from the contracting uterus.[2,4] Although blood volume, heart rate, and cardiac output rise during pregnancy, central venous and systemic blood pressures remain relatively unchanged.[3] This is due to an increased distensability of veins, and an increased capacity within the uterine, skeletal, renal and skin vasculature.[6] Though central venous pressure does not rise during pregnancy, a rise may occur during labor.[5] This is especially true if labor is painful, when there is an increase in the release of maternally-derived catecholamines.[2,3,5,6]

Animal positioning can also have an effect on cardiovascular status. If an animal is placed in dorsal recumbency during surgery, aortocaval compression may occur due to the weight of a gravid uterus being placed upon the vessels.[2-6] This can lead to a decrease in cardiac output, venous return, and subsequently, in renal and uterine blood flow, which lowers oxygen delivery to the fetus. Therefore, the amount of time a patient is positioned in dorsal recumbency should be kept to a minimum.

The significance of these described changes becomes apparent when one considers that most anesthetic drugs are cardiovascular depressants. Care must always be taken to avoid excessive cardiac depression induced by excessive doses of analgesics, sedatives, or anesthetics.

Respiratory System During pregnancy, rising levels of serum progesterone trigger the respiratory center to become more sensitive to arterial carbon dioxide ($PaCO_2$).[2-6] The net result is an increase in minute ventilation to 50% above normal at term.[4] Respiratory al-

Table I. Physiological Alterations Induced by Pregnancy

Parameter	*Change*
Heart Rate	Increased
Cardiac Output	Increased
Blood Volume	Increased
Plasma Volume	Increased
Packed cell volume, hemoglobin, plasma protein conc.	Decreased
Arterial blood pressure	Unchanged
Central venous pressure	Unchanged, increases during labor
Minute volume of ventilation	Increased
Oxygen Consumption	Increased
Arterial blood gases and pH	pH and O_2 tension unchanged; CO_2 tension decreased
Total lung capacity and vital capacity	Unchanged
Functional residual capacity	Unchanged; decreases in late pregnancy
Gastric emptying time and intragastric pressure	Increased
Gastric motility and pH of gastric secretions	Decreased
Gastric Cl and enzyme concentration	Increased
SGOT, LDH, and BSP retention time	Increased
Plasma cholinesterase concentration	Decreased
Renal plasma flow and glomerular filtration rate	Increased
BUN and creatinine	Decreased
Sodium and water balance	Unchanged

kalosis does not have an effect on arterial pH, as long-term renal compensation keeps the level within normal range.[6] As pregnancy progresses, there is also a loss of functional residual capacity (FRC) of the lungs.[2] This is caused by cranial displacement of the diaphragm and other abdominal organs by the gravid uterus. Functional residual capacity is further lost during labor, as there is an increase in pulmonary blood volume secondary to uterine contraction.[2,6] As FRC diminishes, so does the animal's oxygen reserve. This is an important consideration, because as oxygen consumption increases during pregnancy, arterial oxygen tension (PaO_2) remains unchanged.[4] Ventilation may be further increased during labor by pain, apprehension, or anxiety.

As a result of a decrease in FRC at a time when oxygen demands are rising, maternal respiratory depression without supplemental oxygen can easily result in hypoxia and hypercapnea. Increased alveolar ventilation and FRC also result in a more rapid alveolar rate of rise of inhalation anesthetics.[3] The dosage requirements of inhalation anesthetics are therefore reduced in pregnant animals (by 25% for halothane, 32% for methoxyflurane, and 40% for isoflurane).[4] As the minimum alveolar concentration (MAC) value for these agents drops, induction times become much more rapid, and one must be careful not to over-anesthetize the patient.

Gastrointestinal System As pregnancy progresses, the risk of vomiting by the animal increases. Physical displacement of the stomach by the gravid uterus, along with rising serum progesterone levels, lead to a delay in gastric emptying.[2,4-6] Along with this, gastric motility and lower esophageal tone are decreased, whereas hydrochloric acid, chloride, and enzyme concentrations in gastric secretions are on the rise.[2,3,6] The chance of vomiting or regurgitation and aspiration pneumonia, induced by the above, necessitate that the induction of anesthesia and placement of a properly fitting, cuffed endotracheal tube be performed as quickly as possible.

Because of the many physiologic alterations induced by pregnancy, it is evident that the parturient patient is at a much greater risk of experiencing complications during anesthesia for cesarean section than the non-pregnant animal is for routine abdominal surgery.

Drug Transfer Across the Placenta

Drugs used to induce anesthesia in patients presented for cesarean section will invariably affect the fetus. All commonly used anesthetic agents cross the placenta, either by simple diffusion, facilitated diffusion via carrier systems, active transfer, or pinocytosis.[2-6] Of these, the majority cross via simple diffusion. The amount of drug that crosses the placenta to enter the fetal circulation can be described by the Fick equation:[4-6]

$$Q/t = K\frac{A\,(Cm - Cf)}{D}$$

Q/t: Amount of diffused substance per unit time
K: Diffusion constant of a given anesthetic
A: Surface area available for diffusion
D: Thickness of the placenta
Cm: Concentration of the substance in the maternal blood perfusing the placenta (uterine artery concentration)
Cf: Concentration of the substance in fetal blood perfusing the placenta (umbilical artery concentration)

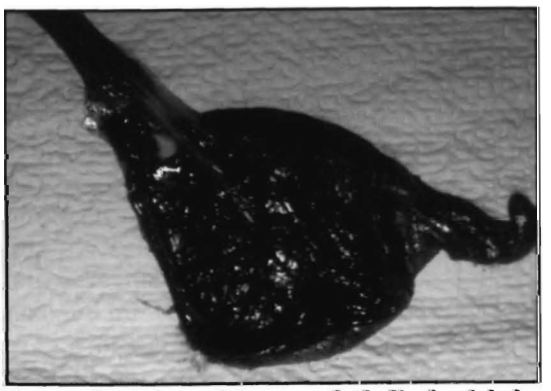
The diffusion constant (K) is unique to each anesthetic agent and is affected by the physiologic events of pregnancy occurring in the dam at the time of administration. The diffusion constant is determined by several factors, including lipid solubility, degree of ionization, molecular weight, and the degree to which the drug is bound to maternal plasma proteins.[5] Drugs with a low molecular weight (MW<500), low degree of protein binding, high lipid solubility, and poor ionization have high K values and diffuse across the placenta rapidly.[4] Conversely, those drugs with a high molecular weight (MW>1000), low lipid solubility, high degree of protein binding, and high ionization cross the placenta slowly.[4] Almost all anesthetic agents have low molecular weight, are partially dissociated under physiologic conditions, are extremely lipid soluble, and have at least some portion which is not bound to plasma proteins. Thus, these drugs cross the placenta readily.

Surface area (A) and thickness of the placenta is determined by each specific species. The dog and cat have thinner endotheliochorial placentas, with comparably larger zonary areas of implantation.[5] In other words, the

surface area of their placentas is large while the diffusion distance is small.

Maternal blood concentration (Cm) of a drug is dependent upon total dose, site and route of administration, rate of distribution and uptake of the drug by maternal tissues, and maternal metabolism and excretion.[6] Therefore, bolusing an anesthetic agent results in rapid initial transfer to the fetus, but rapidly declining maternal concentrations. Alternatively, continuous infusion, repeated bolus administration, and inhalation anesthesia result in continuously high maternal drug concentrations and continuous placental drug transfer to the fetus.

Fetal drug concentrations (Cf) are primarily influenced by simple diffusion across the placenta and are altered by metabolism, redistribution, and protein binding.[2,4,5] Drug metabolism by the fetus is limited. The neonatal liver is not as efficient as an adult liver, because the microsomal enzyme system is not as active as in later life.[5] In addition, only a portion of the blood returning to the fetus from the placenta enters the liver. The other blood containing the drug enters the inferior vena cava via the ductus venosus and mixes with drug-free blood returning from the lower extremities and pelvic viscera.[5] This "detouring" of blood acts to buffer fetal organs from sudden high concentrations of maternally derived anesthetics. Binding of drugs to fetal plasma proteins also may reduce the total amount of free drug available to affect the fetus.[5]



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Dogs and cats have thinner endotheliochorial placentas, with comparably larger zonary areas of implantation. Thus, the surface area of their placenta is large while the diffusion distance is small.

Anesthetic Techniques for Cesarean Section

Satisfactory anesthesia for cesarean section can be induced in several manners, yet certain principles should be followed, regardless of the protocol. Drugs should be chosen in order to minimize fetal depression. As discussed earlier, this can only be accomplished by controlling the depth of maternal anesthesia. It is equally important that the time from induction of anesthesia to delivery of the fetus be kept to a minimum, as prolongation is associated with decreased neonatal viability. Therefore, the majority of patient pre-surgical preparation should be done prior to administration of anesthetic drugs. Another important consideration in the selection of a specific protocol is balancing optimal surgical analgesia with minimal maternal postoperative depression, so that the neonates begin feeding as soon as possible. As previously mentioned, anesthesia for cesarean section can be safe and effective as long as there is familiarity with the particular anesthetic regime, knowledge of the physiological changes that are induced by pregnancy, and foresight into any possible complications that might be encountered.

Cesarean sections can be performed with either regional or general anesthesia. Both of these techniques have advantages and disadvantages that must be considered. However, since most veterinarians are more confident in their ability to induce general anesthesia safely than inducing regional anesthesia successfully, general anesthesia will be the method discussed in this review. Several articles have been written on the protocols for regional anesthesia, and the reader is encouraged to read them if interested in those techniques.

General anesthesia has several advantages when used for cesarean section, including speed of onset and ease of induction, reliability, reproducibility, and controllability. General anesthesia provides optimal surgical conditions along with a relaxed, immobile patient. Tracheal intubation provides a route for maternal oxygen administration, which improves fetal oxygenation and helps to prevent aspiration by ensuring patency of the maternal airway. Also, when performed properly, general anesthesia maintains maternal car-

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Neonates unresponsive to thoracic massage should be intubated with a 16- or 18-gauge intravenous catheter and ventilated at 12 breaths/minute.

diopulmonary function at a desirable level.

General anesthesia does have several disadvantages, however. It causes greater neonatal depression than regional anesthesia, as the latter minimizes the amount of exposure of the fetus to anesthetic drugs.[1] As discussed earlier, overdosage of the pregnant patient can occur easily, because the amount of a drug needed to induce anesthesia is greatly reduced. Conversely, if the plane of anesthesia is too light, the release of maternally-derived catecholamines can result in hypertension and decreased uteroplacental perfusion. This can lead to both maternal and fetal stress, deterioration of cardiopulmonary function, and fetal hypoxia, leading to decreased fetal viability.[1,5,6] Improper tracheal intubation is a leading cause of maternal morbidity due to aspiration of foreign material in women. Fortunately, dogs and cats are relatively easy to intubate.

A variety of protocols are satisfactory for induction of anesthesia for use in cesarean sections. The following example may be used as a guideline to establish a protocol based on the requirements of a specific animal:

1) Premedication should include an anticholinergic such as glycopyrrolate (0.011 mg/kg IM), which helps to decrease salivary secretions, inhibits bradycardia, and increases gastric pH while decreasing intestinal motility.[3,8] Synthetic opioids, such as oxymorphone (0.05 mg/kg IV or 0.1 mg/kg IM), are safe and should be used to decrease the amount of induction agent needed.[3] These agents also have the ability to be reversed, either by an agonist-antagonist such as butorphanol, or by a pure antagonist such as naloxone. Phenothiazines and alpha$_2$ agonists (i.e., xylazine) should be avoided, as their respiratory and cardiovascular depressant effects have a profound effect on fetal viability.[1,6]
2) If possible, oxygen should be adminstered by mask for 3 to 5 minutes prior to induction of anesthesia. Maintaining maternal PaO_2 levels helps in reducing the amount of fetal hypoxia.
3) Induction should be smooth and rapid and may be accomplished in several different manners. Propofol, a substituted isopropylphenol, can be administered intravenously at a dosage of 3-5 mg/kg over 15 seconds or less and will produce unconsciousness within about 30 seconds.[3] This agent will produce dose-dependent decreases in arterial blood pressure and respiratory depression similar to the thiobarbiturates, yet it causes little change in heart rate.[8] Recovery is also more rapid, and there are fewer residual central nervous system effects than those encountered following induction of anesthesia with thiopental.[6] This is an important consideration, in that it is desirable for the dam to assume her motherly duties as soon as possible after surgery.

A single dose of an ultra short-acting thiobarbiturate such as thiopental sodium may be used at a total dose that should not exceed 8 mg/kg.[1] Be aware that repeated doses markedly reduce the chances of delivering viable fetuses, as the degree of respiratory and cardiovascular depression increases with each successive dose.[6]

Induction may also be accomplished by use of an inhalant anesthetic administered by mask or induction chamber in 100% oxygen. This method is usually preferable to the use of injectable induction agents, yet is not without risk. The time needed to induce the animal via this method is typically much longer, which can result in maternal and fetal hypoxia. Remember that all inhalation agents readily cross the placenta, and that the degree of fetal depression depends upon the depth and duration of maternal anesthesia.[1,4] Remember also that because of

changes in maternal physiology at parturition, minimum alveolar concentrations of these agents are greatly reduced, and the chances of overdosage are increased.[3] Isoflurane is the preferred anesthetic agent due to the fact that it causes the least amount of maternal cardiovascular changes, has low solubility in tissues, is rapid in onset, and requires minimal metabolism by the liver.[6,8] Halothane may be used as a second choice. Prior to delivery of the fetus, vaporizer concentrations should be kept at low levels (0.7 to 1.39% and 0.5 to 1%, respectively) to minimize chances of fetal depression.[4] However, these concentrations may be increased as needed for surgical closure.

4) Once the animal has been induced, tracheal intubation should be rapid to gain control of the maternal airway. Coating of the larynx with lidocaine hydrochloride will help in preventing laryngospasm in cats, thereby facilitating intubation.
5) Fluid support should be utilized in the dam (LRS @ 10-20 ml/kg) for volume expansion and maintenance of adequate blood pressure, prior to fetal removal. Following completion of surgery, the dam should be allowed to recover in a quiet, warm area, and the endotracheal tube should be removed. Care should be taken not to remove the tube early, as vomiting and subsequent aspiration can occur during recovery.

Caring for the Newborn

Immediately after delivery, the oral cavity and nasal passages of the newborn should be cleared of any fluid and mucus. Umbilical vessels should be emptied by milking the vessels toward the neonate and clamping them approximately 2 cm from the body wall. The vessels should then be severed from the placenta, thus freeing the newborn from all maternal attachments. A towel may be used to dry the animal and provide warmth. The newborn can then be cradled in the hands and carefully swung in a head down position to help clear the respiratory tract of any remaining fluid. When doing this, the fetal head and neck should be supported to prevent injury.

If respiratory depression is apparent, gentle massage of the thorax may assist breathing, and oxygen should be administered. If a synthetic opioid was used on the dam, an opiate antagonist such as naloxone (0.04 mg/kg in dogs, 0.05 mg/kg in cats) should be available for reversal.[1-3,6,8] A tuberculin syringe fitted with a 25-gauge needle can be used to deliver the naloxone. The antagonist can be administered under the tongue, via the umbilical vein, or subcutaneously. Clinicians must remember, however, that naloxone has a shorter duration of action than many of the opiates, such as butorphanol and fentanyl citrate, and thus "renarcotization" may occur when the naloxone is metabolized and excreted.[4,6,8] Therefore, the newborn to whom naloxone has been given as a reversal agent should be monitored carefully for recurrence of sedation. If this should occur, additional naloxone should be administered.

Newborns that are still unresponsive should be intubated using a 16- or 18-gauge intravenous catheter and ventilated at the rate of 12 breaths per minute.[1] Assisted breathing should continue until the neonate can continue on their own.

For those newborns that continue to be non-responsive, doxapram hydrochloride, a potent respiratory stimulant, may be used as a last resort. For puppies, the recommended dosage is 1-5 mg/kg (approximately 1 to 5 drops from a 20- to 22-gauge needle). For kittens, the dosage is 1-2 mg/kg (1 to 2 drops) administered orally, intravenously via the umbilical vein, or subcutaneously.[1,2,8]

Newborns are extremely susceptible to chilling, especially when the dam is unavailable to provide immediate warmth. Ambient temperatures should ideally be kept between 85-90°F.[5] This can be accomplished by the use of a heat lamp or incubator. After the dam

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Neonates are extremely susceptible to chilling, therefore a heat lamp or incubator is indicated.

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After the dam has recovered from general anesthesia, the newborn pups may be returned to her.

has recovered from general anesthesia, the newborn animals may be returned to her. If regional anesthesia has been used for the procedure, the newborns may be returned to the dam immediately after completion of the surgery.◆

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What's Your Radiographic Diagnosis?

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Presentation

A 4 year-old gelding Quarter horse was presented for evaluation of an incompletely healed wound. Three weeks previously the horse had sustained several skin lacerations while in the pasture. Topical ointment had been applied. The wound on the medial aspect of the left tarsus was forming a small walnut-sized granulation tissue mass. Associated with this was mild generalized soft tissue swelling. The horse was not currently lame and lameness had not been noted initially. A second wound on the right lateral metacarpus was healed. Radiographs of the tarsus were taken. Please see Figures 1 - 3.

Radiographic Findings

The soft tissue abnormalities identified on the physical examination are noted to be at the level of the distal tibia. Deep to the plane of the granulation tissue mass is an area of periosteal new bone formation that is solid except for a focal defect at the junction of its middle and distal thirds. In the cortex is a 1 cm zone of osteolysis that contains a bone opacity that is separated from the cortex. The lesion complex is best seen on the DorsoLateral-PlantaroMedial Oblique (DLPMO) view. The faint lucency of the cortex is seen on both the DorsalPlantar (DP) and LateralMedial (LM) views.

Radiographic Diagnosis

The bone changes are characteristic of sequestrum formation secondary to traumatic cortical osteitis.

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